TP 14405E

Development of Safety Standards for Hydrogen-Fuelled Vehicles – Status Report

Prepared for
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by
Powertech Labs Inc.

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by
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Since some of the accepted measures in the industry are imperial, metric measures are not always used in this report.

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16. Abstract

This report summarizes the current state of knowledge and developments concerning safety standards/guidelines specific to the design and integration of the fuel system in hydrogen-fuelled vehicles. A number of recommendations regarding the development of a future harmonized safety standard for these vehicles are proposed.

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16. Résumé

Ce rapport fait le point sur les connaissances et l'évolution des travaux touchant les normes et lignes directrices de sécurité devant régir la conception du système d'alimentation d'un véhicule à hydrogène et son intégration au véhicule. Il formule en outre des recommandations pour ce qui est de l'élaboration d'une future norme de sécurité harmonisée pour ces véhicules.

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EXECUTIVE SUMMARY

In anticipation of the introduction of hydrogen-powered vehicles, the international community is rapidly developing standards and regulations covering the design and use of hydrogen vehicle fuel systems. Initially, standards developments were limited to individual components for use in vehicle fuel systems, but in the past several years the European Integrated Hydrogen Project (EIHP) has approached the United Nations Working Party on Pollution and Energy (UN GRPE WP 29) to introduce a Global Technical Regulation (GTR) for hydrogen motor vehicles. As a United Nations Economic Commission for Europe (UNECE) contracting party to the 1998 Agreement, Canada is obligated to submit GTRs through its regulatory process. As a result, international developments in hydrogen standards can have a direct effect on future Canadian vehicle safety.

This report summarizes the current state of knowledge and developments concerning safety standards/guidelines specific to the design and integration of the fuel system into hydrogen-fuelled vehicles. In presenting Canadian views and representing Transport Canada's interests at various hydrogen vehicle standards development initiatives, Powertech Labs has been able to provide various recommendations to Transport Canada regarding a future harmonized safety standard – namely:

- The draft UNECE Regulation (EIHP Revision 12b) has been established as the basis for a global standard for the approval/certification of hydrogen fuel systems. The draft document covers basic hydrogen fuel system safety using generally accepted testing protocols. Various tank and component manufacturers and vehicle original equipment manufacturers have already used the document to certify prototype hydrogen vehicles. Transport Canada should continue to monitor the progress of hydrogen component standards such as HGV2, HGV3.1, HPRD1, etc. as they form the basis for some of the tests in the draft UNECE Regulation.
- Transport Canada should participate in the GRPE informal groups that are tasked with the development of the complete GTR.
- Transport Canada should promote the development of a hydrogen vehicle fuel system installation standard, similar in scope to CSA B109 "Natural Gas for Vehicles Installation Code".

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En prévision de l'arrivée sur le marché de véhicules mus à l'hydrogène, la communauté internationale se hâte d'élaborer les normes et règlements qui régiront la conception et l'exploitation des systèmes d'alimentation qui équiperont ces véhicules. Au début, la normalisation ne visait que certains composants du système d'alimentation, mais ces dernières années, le Projet européen intégré sur l'hydrogène (*European Integrated Hydrogen Project* - EIHP) a approché le Groupe de travail sur la pollution et l'énergie des Nations Unies (UN GRPE WP 29) au sujet de l'adoption d'un règlement technique mondial (RTM) sur les véhicules automobiles mus à l'hydrogène. À titre de partie contractante à l'Accord de 1998 de la Commission économique des Nations Unies pour l'Europe (CEE-ONU), le Canada est tenu d'incorporer les RTM à sa réglementation. Il s'ensuit que les initiatives internationales de normalisation des véhicules mus à l'hydrogène peuvent, dans l'avenir, avoir un effet direct sur la sûreté des véhicules mus à l'hydrogène au Canada.

Ce rapport fait le point sur les connaissances et les initiatives en cours dans le domaine des normes et lignes directrices de sécurité touchant la conception du système d'alimentation en hydrogène et son intégration dans le véhicule. Après avoir représenté le point de vue du Canada ainsi que les intérêts de Transports Canada au sein de divers groupes chargés d'élaborer des normes touchant les véhicules à hydrogène, Powertech Labs est en mesure d'adresser diverses recommandations à Transports Canada concernant une future norme de sécurité harmonisée. Voici ces recommandations :

- Il est d'ores et déjà établi que le projet de règlement de la CEE-ONU (révision 12b de l'EIHP) servira de base à une norme mondiale pour l'approbation/la certification des systèmes d'alimentation en hydrogène. Le projet de règlement vise la sûreté fondamentale des systèmes d'alimentation en hydrogène et fait appel à des protocoles d'essai généralement acceptés. Plusieurs fabricants de bouteilles de stockage et de composants, et divers équipementiers automobiles ont déjà utilisé le document pour certifier des prototypes de véhicules mus à l'hydrogène. Transports Canada devrait continuer à suivre de près les travaux de normalisation visant les composants des systèmes d'alimentation en hydrogène (normes HGV2, HGV3.1, HPRD1, etc.) car celles-ci servent d'assise à certains des essais prescrits par le projet de règlement de la CEE-ONU.
- Transports Canada devrait prendre part aux groupes informels du GRPE chargés d'élaborer la version définitive du RTM.
- Transports Canada devrait promouvoir l'élaboration d'une norme d'installation à l'hydrogène pour véhicules qui aurait une portée semblable à celle de la norme CSA B109, *Code d'installation au gaz naturel pour véhicules*.

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GLOSSARY

ANSI	American National Standards Institute
CLEPA	European Association of Automotive Suppliers
CNG	Compressed Natural Gas
CSA	Canadian Standards Association
DIS	Draft International Standard
DOE	Department of Energy
ECE	Economic Commission for Europe
EIHP	European Integrated Hydrogen Project
GRPE	Working Party on Pollution and Energy
GTR	Global Technical Regulation
IGH	Informal Group on Hydrogen / Fuel Cell Vehicles
ISO	International Organization for Standardization
OEM	Original Equipment Manufacturer
OICA	International Organization of Motor Vehicle Manufacturers
SAE	Society of Automotive Engineers
TAG	Technical Advisory Group
TC	Technical Committee
UNECE	United Nations Economic Commissio. for Europe
WG	Working Group

1.0 INTRODUCTION

1.1 Standards

The Canadian Fuel Cell Commercialization Roadmap[1] declares that in the developed areas of the world, the fuel cell and hydrogen industries are poised to provide major improvements in efficiency, greenhouse gas emissions, urban pollution and quality of life. It further states that Canada has the chance to exploit the global leadership position of our companies. Canadian companies and their partners have invested heavily and are global leaders in most facets of hydrogen technologies, from hydrogen production and storage to fuel cell development and associated testing capabilities.

In anticipation of the introduction of hydrogen-powered vehicles, the international community is rapidly developing standards and regulations covering the design and use of hydrogen vehicle fuel systems. Initially, standards developments were limited to individual components for use in vehicle fuel systems, but in the past several years the European Integrated Hydrogen Project (EIHP) has approached the United Nations Working Party on Pollution and Energy (UN GRPE WP 29) to introduce a Global Technical Regulation (GTR) for hydrogen motor vehicles. As a United Nations Economic Commission for Europe (UNECE) contracting party to the 1998 Agreement, Canada is obligated to submit GTRs through its regulatory process. As a result, international developments in hydrogen standards can have a direct effect on future Canadian vehicle safety. Specifically, the design and performance of hydrogen vehicle fuel systems may be affected by the new standards.

As convener of the International Organization for Standardization (ISO) working groups on hydrogen vehicle tanks (ISO TC 197 WG 6) and filling connectors (ISO TC 197 WG 5), and as a member of various technical advisory groups representing Canadian and American compressed natural gas (CNG) and compressed hydrogen standards, Powertech Labs has been involved in harmonizing these standards with the proposed regulation.

1.2 Hydrogen Fuel Systems

Compressed hydrogen fuel systems for vehicles do not simply in)lve storage tanks. There are also check valves, solenoid valves, pressure regulators, pressure relief devices, pressure release valves, fill connectors, thermocouples, pressure transducers, etc. to consider. These devices all have a specific safety operation or control purpose intended to prevent certain safety-related events from occurring. It is important that the purpose of these devices be understood to ensure that future vehicle regulations do not accidentally preclude their use, or do not implement testing protocols that prevent these devices from working properly. A schematic of a typical hydrogen vehicle fuel system is shown in Figure 1.

Currently, compressed hydrogen tanks are being designed to a variety of draft standards since industrial standards for the transportation of compressed hydrogen are not considered suitable for vehicle use. In comparison, the requirements for liquid hydrogen storage have been essentially

[1] Hydrogen and Fuel Cell Committee, "*Charting the Course: A Program Roadmap for Canada's Transition to a Hydrogen Economy*", Government of Canada, 2004.

established due to its long time use in the aerospace industry and in bulk transportation systems. In addition, the demand for liquid hydrogen storage in high-performance applications, such as vehicles, is not prevalent in the automotive industry.

The compressed hydrogen tank manufacturers are currently exploring means of reducing the weight and increasing the pressure and safety of their designs. Although current prototype hydrogen vehicle fuel systems operate at a working pressure of 350 bar, many automotive manufacturers are developing fuel systems at the considerably higher working pressure of 700 bar. It is believed that the 700 bar storage pressure will facilitate the design of fuel cell vehicles with a range comparable to that of petroleum-fuelled vehicles.

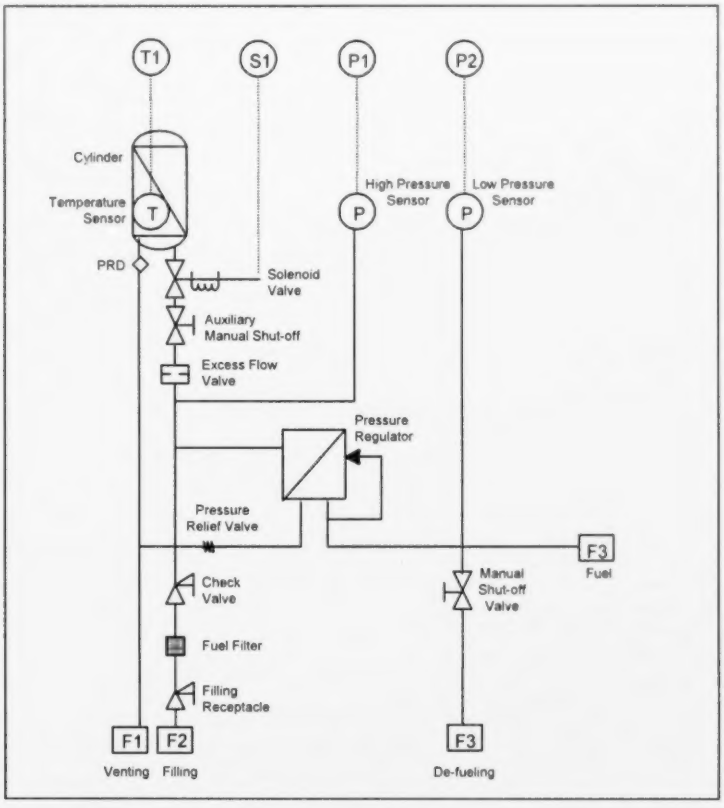

Figure 1: Typical hydrogen vehicle fuel system schematic

The selection of the code or standard to be used in the construction of hydrogen tanks is usually done at the discretion of the user organization. This flexibility is due to the fact that no regulations currently exist to control the design or performance testing of hydrogen vehicle fuel systems. As a result, there is a wide variety of hydrogen fuel systems currently installed on board prototype hydrogen fuel cell vehicles.

The performance of compressed hydrogen tanks varies depending on the standard or draft standard used in the design. Using CNG standards as the basis for compressed hydrogen

standards may be suitable in the interim, but as higher hydrogen working pressures are explored, different test conditions may be required. New hydrogen standards proposals would allow possibly even greater reduction in certain test requirements, while increasing others. For example, the latest revision of the draft UNECE GRPE standard allows for the reduction of fill cycles, but increases the pressure to be used in leak-before-break testing. Also, the proposed hydrogen permeation and allowable leakage rates of components has not been verified.

The peculiarities of compressed gas fuel systems often complicate the maintenance and testing requirements for these systems. A lack of understanding concerning the operation of a CNG fuel system contributed to a tragic accident at a privately operated testing facility located near Montreal. Developing test protocols for hydrogen vehicle fuel systems will therefore require a detailed description of how these compressed fuel systems work, the logic behind the pressure ratings on various portions of the equipment, and factors to consider when performing maintenance on fuel systems.

2.0 PROJECT OBJECTIVE

The overall project goal is to ensure the availability of a harmonized safety standard applicable to hydrogen-fuelled road vehicles that takes into account the concerns of Transport Canada. The main objectives are to:

- Provide qualified support to present Canadian views and interest in the completion of a vehicle fuel storage tank standard for compressed hydrogen currently under development by the UNECE GRPE, and to acquire tanks built to the GRPE standard and conduct tests to verify that performance specifications are met.
- Assess the current state of knowledge and developments concerning safety standards/guidelines specific to the design and integration of the fuel system into hydrogen-fuelled vehicles, and develop a safety standard for hydrogen-fuelled vehicles.

3.0 HYDROGEN VEHICLE FUEL STORAGE STANDARDS

At present, there are no national or international regulations or directives governing the manufacture of hydrogen vehicles. However, there have been several voluntary codes and standards developed by national and international standards-setting organizations, including the American National Standards Institute (ANSI), Canadian Standards Association (CSA), Society of Automotive Engineers (SAE), International Organization for Standardization (ISO), etc. These standards generally address a specific component of hydrogen vehicles, such as on-board storage tanks or pressure relief devices, but not the safety performance and integrity of the entire hydrogen fuel system and whole vehicles.

Throughout the two-year term of this contract, Powertech attended virtually all of the task group meetings relating to hydrogen vehicle standards as defined by the above national and international standards-setting organizations. Following is a summary of the current status of each standard.

3.1 North American Standards

ANSI/CSA NGV2 – Basic Requirements for Compressed Natural Gas Vehicle (NGV) Fuel Containers

- This standard covers vehicle fuel cylinders for CNG in the U.S. It is referenced by Transport Canada along with CSA B51 in the Motor Vehicle Regulations for CNG vehicles (301.2).
- At the December 2003 Technical Advisory Group (TAG) meeting of NGV2 it was agreed to expand the standard to include hydrogen.
- Originally it was agreed to split the standard into two parts – NGV2 for CNG and HGV2 for hydrogen.
- At the May 2004 meeting it was agreed that both parts should be amalgamated into one standard – the NGV2/HGV2 standard.
- Numerous teleconferences have taken place to address outstanding technical issues.
- The parts were amalgamated and the document was balloted in January 2005 (after a final teleconference in January to ensure editorial changes were accepted) with formal publication by ANSI in April 2005.

CSA B51 Part 2 – High Pressure Cylinders for the On-Board Storage of Natural Gas as a Fuel for Automotive Vehicles

- This standard covers vehicle fuel cylinders for CNG in Canada. It is referenced by Transport Canada along with NGV 2 in the Motor Vehicle Regulations for CNG vehicles (301.2).
- At a meeting in July 2004, the Technical Subcommittee for CSA B51 recommended that the standard be expanded to include hydrogen – only a few technical changes were required to accommodate hydrogen properties.
- In August 2004 the Chief Inspectors of Canada for pressure vessels agreed to accept the changes to CSA B51 to include hydrogen.
- In November 2004 the CSA B51 Steering Committee met and agreed to expand the scope of CSA B51 to include hydrogen.
- The CSA B51 Part 2 standard "High Pressure Cylinders for the On-Board Storage of Natural Gas as a Fuel for Automotive Vehicles" and the CSA B51 Part 3 standard "Compressed Natural Gas Refuelling Station Pressure Piping Systems and Ground Storage Vessels", have accordingly been revised to include the requirements for hydrogen. CSA B51 Part 3 standard is currently out for public comment.

ANSI/CSA NGV3.1 – Fuel System Components for Natural Gas Powered Vehicles

- This standard includes performance requirements for CNG fuel system components, including valves, pressure regulators, check valves, pressure measurement devices, etc.
- A TAG meeting was held on October 19, 2004 in Cleveland, Ohio.

- The standard is being revised by the TAG to align itself with the requirements of the ISO 15500 Parts 1 – 19 series of standards. Twenty-one task groups were created to reformat the document.
- The hydrogen version of NGV3.1, tentatively referred to as HGV3.1, will follow on the development of the revised NGV3.1. The work on this hydrogen document is likely to commence in six months.

ANSI/IAS PRD1/HPRD1 – Pressure Relief Devices for Natural Gas Vehicle Fuel Containers

- This standard specifies the performance requirements for pressure relief devices for CNG cylinders.
- A hydrogen version of this standard, entitled HPRD1, is under development.
- A teleconference was held on August 30, 2004, to discuss outstanding technical issues identified at the previous TAG meeting.
- An integrated document was due to be circulated amongst TAG members in October 2004, but this has not occurred yet.

CSA B109 – Natural Gas for Vehicles Installation Code

- This code provides provisions for the installation, servicing and repair of natural gas-powered vehicle fuel systems.
- There are currently no plans for developing a hydrogen version of this code, although numerous prototype hydrogen fuel cell and hydrogen internal combustion engine vehicles are currently in operation in Canada.

On February 15, 2005, CSA America (the standards agency responsible for HGV2, HPRD1 and HGV3) announced that a significant portion of the U.S. Department of Energy (DOE) budget for hydrogen codes and standards development had been allocated to other areas, and that funding for this activity would be significantly reduced in subsequent years. As a result, standards development work on HGV2, HPRD1 and HGV3 has continued at a much slower pace.

3.2 ISO Standards

ISO TC 197 (Hydrogen Technologies)

WG 5 – ISO/DIS 17268 – Compressed Hydrogen Surface Vehicle Refuelling Connection Devices

- ISO/DIS 17268 has adopted the latest published version of SAE J2600 in accordance with the ISO Fast Track Rules.
- Many of the hydrogen vehicle refuelling connectors and station nozzles are designed and tested per SAE J2600.
- Currently the standard defines vehicle receptacle dimensions for 250 and 350 bar service pressure only.
- ISO/DIS 17268 completed balloting on July 5, 2004 – the document was approved with a 75 percent positive rating.

- The WG has agreed to continue working on the document to resolve all outstanding technical comments that were received during the DIS vote.
- ISO/DIS 17268 will undergo a second round of DIS voting once all technical comments are resolved.

WG 6 – ISO/DIS 15869 – Gaseous Hydrogen and Hydrogen Blends – Land Vehicle Fuel Tanks

- ISO 15869 for Land Vehicle Fuel Tanks is a joint working group between TC 197 on Hydrogen Technologies and TC 58/SC 3 on Gas Cylinders – Design. In 2001 the P-members of both Technical Committees agreed to the circulation of a Committee Document as a Draft International Standard by an acceptance vote of 80 percent by TC 197 members and 71.4 percent by TC 58/SC 3 members. All comments received during the balloting process were reviewed at a meeting in Paris in October 2001.
- At this point, further progress in the development of the ISO standard was delayed due to the activities of the EIHP.
- The EIHP has been involved in developing draft regulations for compressed hydrogen vehicle systems, including fuel tanks. At a meeting of the UN GRPE WP29, the EIHP proposed to undertake the development of ECE regulations for hydrogen-fuelled road vehicles and equipment. The eventual objective would be to develop a UN GTR.
- The UN GRPE WP29 requested EIHP to harmonize its proposed regulation with ISO working groups. As a result, a UNECE GRPE ad hoc Working Group "Hydrogen Vehicles – Onboard Storage Systems" was established in June 2001 to undertake this harmonization. The secretaries from TC 22 (Road vehicles), TC 58 (Gas cylinders) and TC 197 (Hydrogen technologies) were requested to nominate experts to the GRPE ad hoc Working Group. The secretaries of both TC 58/SC 3 and TC 197 nominated the convener of the Joint TC 58/TC 197 Working Group 6 (Craig Webster of Powertech Labs Inc.) to participate in the GRPE ad hoc Working Group.
- Numerous meetings between the GRPE ad hoc Working Group and the Joint TC 58/TC 197 Working Group 6 (also known as the GRPE/ISO group of experts) have been held over the past year with the objective of combining the best of both proposed documents to produce a harmonized text. The Joint TC 58/TC 197 Working Group 6 is composed primarily of cylinder manufacturers and regulatory agencies, while the GRPE ad hoc Working Group is composed primarily of vehicle manufacturers and regulatory agencies. As a result, there is an interesting difference in perspective between the cylinder manufacturers and the vehicle users, with the regulatory agencies in the middle.
- Due to a difference in philosophies between the two groups, it was determined that complete harmonization of the two documents could not be achieved on a specific item concerning the design of all-metal storage tanks. It was therefore believed that the harmonization process had proceeded as far as possible at that time. Consequently, the ISO/CD 15869 has been modified such that the technical requirements are identical to those in Revision 11 of the Draft ECE Compressed

Gaseous Hydrogen Regulation, except for the issue regarding the all-metal storage tanks.

- Since the completion of the harmonization process, Revision 12 of the Draft ECE Compressed Gaseous Hydrogen Regulation has been issued, adding stainless steels and welded manufacturing processes. However, there is a need to move ahead with the ISO process, thus these issues will be reviewed by the Joint TC 58/TC 197 Working Group 6 at some future date.
- The incorporation of the harmonized changes from Revision 11 into ISO/CD 15869 has been complicated by the fact that both documents have completely different formats.
- ISO/DIS 15869 was completed and circulated to the membership worldwide as of February 2004. The completion of voting occurred on June 15, 2004.
- The standard was divided into five parts – three of the five parts were accepted and two of the five parts were rejected.
- The comments were reviewed at two subsequent WG 6 meetings on January 17-19, 2005 in Paris and April 4-6, 2005 in Cologne. The five-part standard has now been recombined into one document. It will be circulated for a second DIS vote.

3.3 European Integrated Hydrogen Project (EIHP)

- During the 126th Session of Working Party 29 (WP.29) in March 2002, the Executive Committee of the 1998 Global Agreement adopted a Program of Work. Under the Program of Work, WP.29 has agreed to undertake work to begin exchanging information on fuel cell / hydrogen vehicles. In 2002, two proposals for draft regulations for vehicles powered by liquid and compressed gaseous hydrogen, developed under the EIHP, were submitted to WP.29. The Working Party/Group of Experts on Pollution and Energy formed an Informal Group on Hydrogen/Fuel Cell Vehicles (GRPE/IGH) to discuss and evaluate these draft proposals.
- The IGH, under the chairmanship of Germany, has met several times since 2002 to discuss the two proposals. The Contracting Parties represented on the IGH, in addition to Germany, are the European Union, France, Japan, the Netherlands, and the U.S. Representatives from the European Association of Automotive Suppliers (CLEPA), ISO, and the International Organization of Motor Vehicle Manufacturers (OICA), as well as individual vehicle manufacturers, also participate.
- At its 46th Session in May 2003, the GRPE considered the two draft regulations as potential ECE regulations under the 1958 Agreement. The proposals are documented on the UNECE website as formal document (TRANS/WP.29/GRPE/2003/14) for liquid hydrogen and informal document (ID #6-Revision 12a, 1.09.03) for compressed gaseous hydrogen. Following a discussion of the proposed regulations, the GRPE concluded that the draft regulations were not ready for adoption and postponed action on the proposals. Specifically, the proposals were not comprehensive enough, as they addressed only individual components. The evaluation of the entire hydrogen fuel system, including a fuel system crash test, was not considered by the proposals. In addition, the draft regulations were very design specific, with the potential of constraining future technological innovations. Finally, the rationale to introduce the draft regulations under the 1958 Agreement was put to

question, and the GRPE Chairman recommended that, given the global nature of the automotive industry, the group take a more global approach when considering the regulations for hydrogen vehicles.

- The GRPE Chairman also directed the IGH to work with Japan, the U.S., the European Union and other interested delegations to develop a roadmap for the assessment of the hydrogen technologies for motor vehicles, outlining any necessary research, development and testing that would be needed for the development of potential GTRs. The discussion of these issues was resumed at the next session of the GRPE in January 2004.
- With respect to the application of a potential global technical regulation for hydrogen vehicles, the GTR should extend to any vehicles powered entirely by hydrogen and vehicles using hydrogen as a complementary fuel (hybrid vehicles). Furthermore, the regulation should cover individual components and address the safety performance and integrity of the entire hydrogen fuel system. These requirements should be written, to the extent possible, in terms of performance, as design-specific requirements may potentially constrain future hydrogen-related technological innovations and methodologies.
- The GRPE informal group met May 13-14, 2004, in Washington, D.C., to create an action plan (roadmap) to develop a Hydrogen/Fuel Cell GTR.
- The roadmap for a GTR was presented at the 48th GRPE meeting in Geneva June 1-4, 2004.
- The roadmap suggests that the GTR(s) should extend to original equipment manufacturer vehicles powered or equipped by hydrogen as well as their associated fuel storage systems, and should cover main aspects as identified by the informal group for:

    - On-board storage system safety (safety of tank and components, leakage, etc.)
    - Whole vehicle safety (crashworthiness, fire safety, explosion protection, etc.)
    - Other aspects (e.g., pollutant emissions, fuel consumption, recycling, etc.)

- The detailed scope, content, test requirements and the number of GTRs required are to be finalized at a later date after the approach is confirmed by the GRPE.
- The informal group agreed that the goal is to develop regulations, harmonized and performance-based to the greatest extent possible, taking into consideration benefits and cost effectiveness of the new GTR(s).
- The drafting of the GTR(s) is expected to commence in September 2004 and conclude in 2010.

4.0 RESULTS OF HYDROGEN TANK TESTS PER DRAFT UNECE REGULATION

The draft UNECE Regulation (EIHP Revision 12b) contains performance requirements for the individual fuel system components, including tanks, valves, pressure regulators, pressure relief devices, etc. The testing protocol for each specific component has been based on generally accepted test procedures found in ISO 15869 (hydrogen tanks), ISO 17268 (hydrogen refuelling connectors), NGV3.1 (fuel system components) and PRD1 (pressure relief devices). As stated in Section 3, these tests will likely address on-board hydrogen storage system safety as part of the future GTR. Other tests covering crashworthiness, pollutant emissions, fuel consumption, etc. will be devised through to 2010.

In order to determine the efficacy of the proposed UNECE Regulation (EIHP Revision 12b), a number of prototype reduced cycle life 700 bar hydrogen fuel tanks of 130 L water capacity were subjected to the performance tests specified in the draft. The test results are shown in Table 1.

Table 1: Results of performance tests per EIHP Revision 12b

EIHP Rev. 12b Test	Serial Number	Test Results
Ambient temperature pressure cycle	J2434	Dome leak at 6,554 cycles
	J2429	Sidewall leak at 7,772 cycles
Hydrostatic burst	J2432	Burst at 1,968 bar
	J2436	Burst at 2,121 bar
	J2439	Burst at 2,010 bar
Accelerated stress rupture	J2430	Burst at 1,974 bar after 1000 hr hold
Flaw tolerance	J2443	Sidewall leak at 7,204 cycles
Bonfire	J2438	PRD vent after 132 seconds
Gunfire	J2427	Tank vented safely

The reduced cycle life tank met all of the performance requirements of the UNECE Regulation (EIHP Revision 12b).

This tank design was recently registered for use in Canada for hydrogen vehicle service at a working pressure of 700 bar for a reduced cycle life of 6,000 cycles or 6 years.

5.0 RECOMMENDATIONS TO TRANSPORT CANADA

- The draft UNECE Regulation (EIHP Revision 12b) has been established as the basis for a global standard for the approval/certification of hydrogen fuel systems. The draft document covers basic hydrogen fuel system safety using generally accepted testing protocols. The document has already been used by various tank and component manufacturers and vehicle OEMs to certify prototype hydrogen vehicles. Transport Canada should continue to monitor the progress of hydrogen component standards such as HGV2, HGV3.1 and HPRD1 as they form the basis for some of the tests in the draft UNECE Regulation. Should Canada adopt the GTR, Transport Canada will be in a better position to determine whether the recommended testing protocol meets its needs.

- Transport Canada should participate in the GRPE informal groups that are tasked with the development of the complete GTR, which will include the following elements:

    - On-board storage system safety (safety of tank and components, leakage, etc.)
    - Whole vehicle safety (crashworthiness, fire safety, explosion protection, etc.)
    - Other aspects (e.g. pollutant emissions, fuel consumption, recycling, etc.)

- Transport Canada should promote the development of a hydrogen vehicle fuel system installation standard, similar in scope to CSA B109 "Natural Gas for Vehicles Installation Code".